

Construction Technology of Deep Foundation Pit around Existing Subway Project

Xin Lei*, Zhiyuan Chu, Wenlong Li, Haobin Wu, Xiaolong Li

China Construction Second Engineering Bureau Ltd., Dongguan, Guangdong, 25300, China

**Corresponding author*

Keywords: Subway connectivity, support construction, subway disturbances, deep foundation pit construction

Abstract: The project of Cowin City Plaza is adjacent to the existing Metro Line 2, and the basement floor is connected to the existing Metro Line 2 station hall floor, and the supporting structures on both sides of the connection port need to be connected with the original subway support structure; However, in the early stage of design, due to the lack of completion drawing data of the subway structure, some parts may be inaccurate, which increases the construction difficulty of the handover location, in order to ensure the protection of the subway structure during construction. To prevent disturbance of the existing subway structure due to the construction of the deep foundation pit, the project studies the foundation pit support construction at the subway junction location, conducts field surveys, communicates with the design in advance, optimizes the support structure at the connection port, and adjusts the original pile to high-pressure rotary blast pile to avoid greater disturbance to the existing subway structure during large-scale mechanical construction.

1. Introduction

With the development of urban land, the available land area is gradually reduced. Meanwhile, with the demand of people for convenient travel, the development of the surrounding sites near the subways, stations and highways has become more and more intensive, especially for the development of the location around the subway station. As a rapid rail transit built in cities with fast and large-volume of electric traction, subway lines are usually arranged in underground tunnels. As one of the main means of transportation for people to pass through, subway stations and sections are closely related to passengers. Metro stations are equipped with a large part of technical equipment and operation management system in subway operation. It plays an important role in ensuring the safe operation of the subway.

In that development of the commercial complex near the metro area, most of the commercial complex considers connecting with the existing subway in order to improve the traffic flow of the commercial people. At the position where the support of the communication port is connected, it becomes the weak region of the whole support system and the region with the greatest influence on the subway, thus not only ensuring the soil retaining effect at the interface position, meanwhile, the waterproof effect of the position shall be considered, so as to avoid the problems of support leakage

and deformation affecting the subway structure during Earthwork. During the construction and design process of the deep foundation pit adjacent to the subway line, the supporting parameters and plan of the foundation pit should be carefully designed according to its special geological conditions and construction conditions, so as to ensure the construction safety and stability of the deep foundation pit adjacent to the subway line.

2. Project Overview and Analysis of Key Points and Difficulties

The total land area of this project is 48433.16 m², the total building area is 125787.12 m², the total building area of No. 1 commercial building is 2059.23 m², the total building area of No. 2 commercial building is 9,482.17 m², the total building area of No. 3 commercial building is 55528.79 m², and that of No. 4 basement is 19762.23 m², and the foundation form is natural foundation; No. 5 basement is 38954.70 m². The foundation form is cast-in-place pile foundation; the maximum number of floors on the ground is 4 floors. The maximum building height is about 24 m. The maximum span is about 46 m, which adopts a frame structure system, some of the large-span locations are steel reinforced concrete structures.

Line R2 of Dongguan Metro passes through the middle of No. 4 and No. 5 basement of the project. The station is east-west and crosses Shilong Town and Chashan Town. Dongguan Metro Line R2 is vertically intersected with Guangzhou-Shenzhen Railway. The station passes under the railway block and the station building on the side of Shilong Town of National Railway Station. However, the main structure of Metro Line R2 is separated from that of Guangzhou-Shenzhen Railway. Dongguan Railway Station of Dongguan Metro is an underground two-floor island platform station with a platform width of 13 m. Since the planned ground elevation of the square on Shilong side is 7 m higher than that on Chashan side, the station is a two-floor underground structure covered by soil on Shilong side. The station hall of Chashan side is higher than the planned elevation of the subway and is provided with elevated lane of railway station building. The greening grass slope is used for covering; the platform floor is one floor.

The project is divided into east and west plots, with Dongguan Metro Line R2 passing through the middle of the two plots. The minimum horizontal clear distance between the excavation side line of No. 4 foundation pit and the outer side line of the entrance/exit structure A is 0.52 m, the minimum horizontal clear distance from the outer edge line of the entrance structure B is 3.77 m, and the minimum horizontal clear distance from the outer edge line of the No. 1 ventilation pavilion structure is 4.85 m. The minimum horizontal clear distance between the excavation side line of No. 5 foundation pit and the outer edge line of the entrance/exit structure F is 2.73 m; the minimum horizontal clear distance from the outer edge line of the entrance/exit structure E is 4.4 m, and the minimum horizontal clear distance from the outer edge line of the No. 4 ventilation pavilion structure is 1.28 m. The subway station structure is located at the lower side of foundation pit No. 4 and No. 5. At the same time, limited by the site and subway structure, the irregular shape of foundation pit and insufficient construction site have brought great difficulties to the support design and construction of the project^[1-3].

3. Design of Foundation Pit Adjacent to Metro

As the project is relatively close to the subway, the foundation pit design shall fully consider the disturbance to the subway structure during the foundation pit support construction^[4], so as to ensure the safety of the foundation pit, as well as the safe operation and use of the existing subway line. Thus during the period of design of foundation pit support structure, we organize to study it, select two supporting plan, and analyze the two plans.

Plan I: Construction plan of cast-in-place pile + high-pressure jet grouting between piles at the

side close to the subway

This plan is a combination of cast-in-place pile and high-pressure jet grouting pile, wherein the cast-in-place pile is subjected soil side pressure, and the high-pressure jet grouting and the cast-in-place pile are occluded to form a water-stopping curtain^[5]; and make full use of the characteristics of the two processes and save resources and costs. It has the advantages of small construction area, small vibration, low noise, and will not bring vibration influence and noise to the surrounding buildings; however, it is easy to pollute the environment, so it is not suitable for special soil that cannot solidify the sprayed slurry.

Plan II: Construction plan of adopting bored secant pile at the side close to the subway

Through the arrangement of the piles to form a mutually occluding pile wall, while the soil retaining and supporting can effectively play a role of water stopping. Due to the mutual engagement of the plain and the reinforced to form a wall body, the two have a common effect when the wall body is stressed and deformed. For the reinforced pile, the existence of the plain pile increases its bending strength to a certain extent and enhances the stability of the whole pile. Meanwhile, this supporting form is a non-squeezed soil pile, in the pile construction process, to ensure the soil around the construction pile position is not squeezed, i.e. the pile position is not expanded, the concrete is filled evenly during concrete pouring, the appearance of the pile body is neat and tidy, and adjacent buildings are not influenced.

Since the project is close to the subway, the special rainwater and sewage drainage system is arranged above the subway. During the construction, attention shall be paid to the protection of the pipeline above the subway to prevent sewage from entering the drainage and sewage system of the subway, causing in pipeline blockage; meanwhile, considering the importance of the subway and minimizing the disturbance to the subway structure, so the construction plan of bored secant pile shall be selected.

4. Foundation Pit Supporting and Protective Construction

In order to minimize the operation risk of the subway track and reduce the influence of earth pressure and excavation dynamic load on the rail diaphragm wall, the section supporting piles near the subway line should be constructed simultaneously at the first time after entering the site. The earthwork can be started only after the cast-in-place pile support meets the design requirements.

4.1. Construction Process

Preparation before construction: setting out and positioning; completing cast-in-place pile, high-pressure jet grouting pile, column pile and column, crown beam and inner support at ground elevation;

After the concrete strength of the crown beam and the support reaches 80% of the design strength, excavating the earth layer by layer to the elevation of the pit bottom and constructing the 80-thick C20 hanging mesh concrete of the supporting pile;

Construction of the bottom plate of the second floor of the main structure and timely construction of the corresponding elevation of the concrete slab;

The construction main structure is provided with a layer of bottom plate (floor) and the outer side of the basement is back-filled or made as a waterproof layer, and then a support-replacing concrete slab corresponding to the elevation is constructed;

After the concrete strength of the main structural member and the concrete plate for replacing the support reaches 85% of the design strength, removing the support;

The main structure of the construction shall be up to ± 0.000 m, and the outside of the basement shall be back-filled.

4.2. Deployment of Foundation Pit Supporting and Protective Construction

In order to minimize the operation risk of the subway track and reduce the influence of earth pressure and excavation dynamic load on the rail diaphragm wall, the section supporting piles near the subway line should be constructed simultaneously at the first time after entering the site. The earthwork can be started only after the cast-in-place pile support meets the design requirements.

(1) Construction stage of 4# basement foundation pit support

Two jet pile diggers are set. No. 1 jet pile digger: KL→MN→lattice column foundation; No. 2 jet pile digger: OP→QJ. Before the subway protection agreement comes down, the supporting piles and column piles outside the subway protection area shall be constructed first. Then construct the cast-in-place piles in KL and MN areas in the west and the column piles outside the protection area. After the subway protection area can be constructed, the second jet pile digger will be mobilized to construct sections OP and QJ. See Fig. 1 for details of the construction sequence.

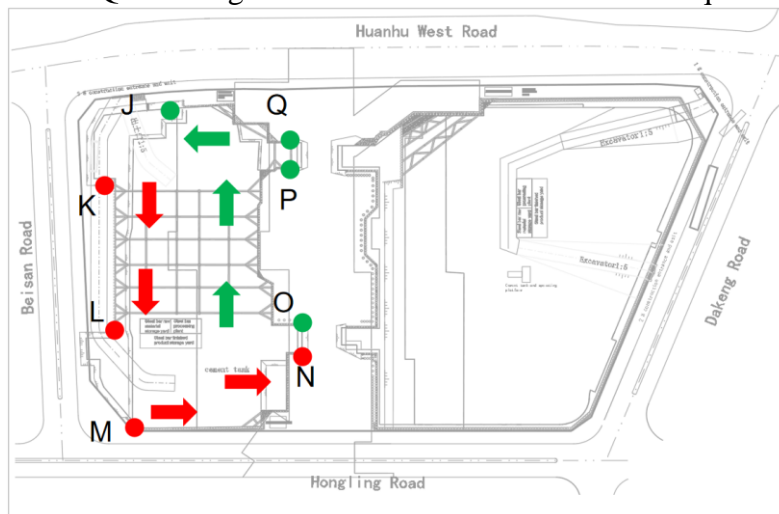


Figure 1: Construction Sequence of 4# Basement Foundation Pit Support

(2) Construction stage of foundation pit support of 5# basement

Set 4 jet pile diggers, 2 triaxial mixing piles and 2 anchor rope machines; the construction sequence of mixing piles: A→B; B→D.

Construction sequence of cast-in-place pile: A→B; B→C; construction sequence of bored secant pile: C→D; G→A. Before the metro protection agreement comes down, the north and east support areas of the foundation pit shall be constructed first. According to the site conditions, the north mixing pile construction shall be carried out first. The No. 1 triaxial mixing pile machine shall be used for construction of section AB, No. 2 three-shaft mixing pile machine shall be used for construction of section BC. Two mixing pile machines shall be used for construction at the same time. After the mixing pile reaches the strength, the cast-in-place pile shall be constructed at the same time. Section AB shall be constructed by No. 1 jet pile digger and section BC shall be constructed by No. 2 jet pile driver. After the construction of No. 3 section, the 4# jet pile digger enters the site. Construct occlusive piles from point F to both sides. See Fig. 2 for the construction sequence of FC section and FA section constructed by No. 3 jet pile driver.

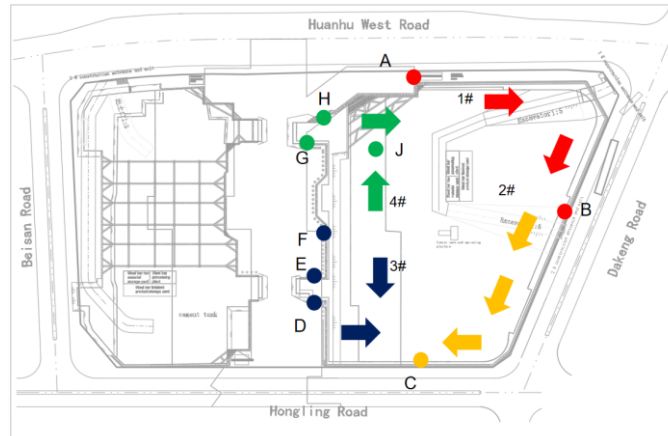


Figure 2: Construction Sequence of Foundation Pit Support of 5# Basement

5. Earthwork Construction

5.1. General Principles

Before the commencement of construction, the allocation plan of earthwork and filling shall be formulated first, and the earthwork balance allocation shall be done comprehensively considering the reasonable distance of earthwork and the reasonable construction sequence. Before construction, the underground structures and various underground pipelines and elevations within the site shall be identified, and necessary measures shall be taken to avoid damage during construction. The surrounding sections of foundation pit shall be excavated in layers, sections and symmetrically in accordance with the principle of support before excavation.

5.2. Precautions for Earthwork

During the foundation pit is excavated within the scope of subway protection line, the difference of earthworks on both sides of the same section structure of the subway shall be no more than 2 m, so as to prevent uneven stress on one side of the original subway structure and abnormal deformation or displacement of the subway structure.

According to the geological data, the buried depth of groundwater level in the site is relatively shallow. Open ditch drainage measures shall be adopted in the site. Several sumps shall be dug in the site. With the increase of excavation depth, the sumps will be deepened gradually. At the same time, a three-stage sand sedimentation basin is set at the outlet of the drainage ditch at the upper part of the foundation pit. The water in the pit shall be pumped to the grit chamber for sedimentation and then discharged into the municipal pipe network.

Excavation of foundation pit shall be adopt the way of full-scale or bench-type excavation by layers; the thickness of each layer shall not be greater than 4 m, and the excavated ramp shall be arranged according to the construction arrangement and drawing requirements^[6].

For each excavation section of working face, reinforcement planting, reinforcement mesh laying and shotcrete support shall be completed within 24 hours.

Reasonable excavation sequence is arranged to minimize the exposure time of pit slope. For each layer, the earthwork at the edge area of the foundation pit can be excavated first, and then the middle area of the foundation pit can be excavated after the earth nail construction working face is provided. Attention shall be paid to avoid damage to drainage ditch and other facilities during earth transportation.

With the excavation depth in place, a simple sump shall be arranged immediately. The next layer of soil shall be excavated after drainage. The principle of drainage before excavation shall be followed.

During excavation, if medium (strong) weathered rock is not easy to excavate, it should be treated according to the situation: if it is a small area of moderately weathered layer, it shall be excavated with pneumatic pickaxe or crowbar and hammer with excavator; if it is a large area of moderately weathered layer, blasting machine shall be used for demolition and construction with excavator. However, attention should be paid to the construction of the gun machine to avoid damaging the foundation pit supporting structure and the existing subway structure.

6. Metro Protection Measures

6.1. Protective Measures in Support Construction Stage

(1) Impact of spoil stacking

If the waste soil excavated by the jet excavator is not transported away in time, it will squeeze the soil nearby and affect the safety of the subway. Therefore, after the dregs are excavated, they are transferred as soon as possible, transported to the location of the foundation pit away from the subway station by excavators and transport trucks, and then centrally transported to the professional dregs. Excavators shall be used for loading. Mud and slag shall be transported by special vehicles. The vehicles shall be covered. When driving from the construction site to the existing road, the vehicles shall be washed clean to prevent mud from entering the road surface.

(2) Loads from construction machinery

In order to avoid excessive load of jet pile digger, crane and concrete transport vehicle during driving, 6 m wide and 15 cm thick C20 plain concrete construction access road shall be poured on the east side of foundation pit. Before construction, the foundation of the site shall be leveled by excavator, and the ground shall be rolled by small-sized plate rammer. After the completion of the above work, the concrete foundation shall be constructed. Through the integral pouring of the concrete foundation, the mechanical load is evenly dispersed, thereby reducing the mechanical pressure on the soil.

6.2. Protective Measures at Earthwork Stage

The excavation of foundation pit is an unloading process. With the excavation of foundation pit, the change of stress field in the soil causes the displacement and sliding of surrounding soil towards the excavation direction of foundation pit, resulting in vertical and horizontal displacement of surrounding buildings.

Earthwork will affect the soil outside the metro station. In order to ensure that the soil displacement does not exceed the safety value, the construction quality of jet-excavated pile and internal support must be strictly controlled. Earthwork can be carried out only after the supporting structure meets the design requirements^[7]. When water leakage occurs in the foundation pit, resulting in ground subsidence around the pit, the excavation shall be stopped immediately, leakage stoppage and repair shall be carried out in time or water-stop curtain shall be added, back-filling shall be carried out, and deformation observation shall be strengthened.

The Earthwork shall follow the principles of layering, symmetry and time limitation. Over-excavation is strictly prohibited. It is strictly prohibited to excavate directly to the bottom of the foundation pit in a large area. If necessary, counter-pressure soil shall be reserved in the foundation pit. The excavation sequence shall be from west to east, so as to reduce the unloading and exposure time of the foundation pit caused by the excavation of the foundation pit earthwork and avoid the adverse impact on the supporting structure of the subway. When the excavation reaches the designed

elevation of the foundation pit bottom, the cushion layer and waterproof layer should be applied immediately, and the basement structure should be poured. The implementation must be continuous operation to avoid the risk of long-term exposure of the foundation pit, and it is strictly forbidden to pile soil on the side of the subway station.

6.3. Other Protective Measures

According to the Geo-technical Engineering Investigation Report, Main Body Design Drawing, Foundation Pit Design Drawing and Metro Safety Assessment Report of the Project, the following measures will be taken for the protection of tracks to ensure that the construction of foundation pit works will not affect the surrounding tracks:

1) Before the implementation of the project, the construction can be carried out after obtaining the permission of the rail company and other relevant urban rail transit management departments.

2) Before the construction of deep foundation pit, relevant investigation and analysis shall be carried out on the current situation of the supporting structure adjacent to the subway station, and the existing monitoring data shall be collected^[8].

3) During the foundation pit construction, the principle of monitoring first and then construction shall be followed. A qualified third-party monitoring unit shall be entrusted to monitor the deformation of the supporting structure of the subway station, and the deformation and water level monitoring of the foundation pit close to the subway station shall be strengthened, and the monitoring data shall be timely fed back^[9].

4) During the construction of foundation pit support, it is strictly forbidden to carry out pile loading near the top of foundation pit on the subway side, and eye-catching signs and fixed fences shall be set in the stacking limit area.

5) Before the excavation of the foundation pit, the water stop curtain of the foundation pit shall be provided, and the dewatering plan outside the foundation pit shall not be used to avoid water and soil loss caused by pumping and discharging a large amount of underground water, so as to ensure the stability of formation around the subway station and avoid settlement. Ensure the water-tightness of the foundation pit enclosure structure, especially the construction quality of the jet grouting pile between piles and the water-stopping function of the foundation pit structure curtain^[10].

6) The project department will optimize the construction period and minimize the exposure time of the foundation pit as much as possible, thereby reducing the construction safety pressure and risks. The concrete support shall be completed at the foundation pit site as soon as possible to form a complete stress system for the support.

7) If it is found that the displacement of the foundation pit exceeds the design control, the construction shall be stopped immediately, the back pressure backfill in the foundation pit shall be carried out in time, the monitoring frequency of the foundation pit shall be strengthened, and the monitoring frequency of deformation of the surrounding soil shall be strengthened. And the surrounding soil should be strengthened by grouting reinforcement if necessary.

6.4. Emergency Treatment of Subway Deformation

1) When it is found that the deformation of the jet-excavated pile, surrounding soil mass and subway supporting structure exceeds the warning value, the excavation of the foundation pit shall be stopped immediately, and the deformation development shall be controlled by soil stacking and back pressure.

2) The project department will promptly notify the construction unit and subway company, organize on-site meetings for discussion, confirm the causes of deformation, and discuss follow-up measures.

3) According to the position of the deformation, check the jet-excavated pile and internal support. In case of excessive deformation or surface cracks, steel support shall be added at the problem, and the pit bottom shall be reinforced (such as grouting and high-pressure jet grouting, etc.) to improve the resistance of the passive area. Meanwhile, the surrounding supports shall be rechecked to see if there is any support looseness. If slack support is found, steel wedge jacking or additional support should be applied immediately.

6.5. Monitoring of Metro Tracks during Construction

1) The qualified third-party monitoring unit shall be entrusted to monitor the settlement and displacement of the subway section tunnel. The Project Department shall arrange professional survey personnel for monitoring. Meanwhile, the Project Department shall conduct daily patrol inspection for the subway tunnel together with the monitoring unit, and formulate corresponding plans and measures, adopt information construction, and timely feedback, summary and processing of relevant information.

2) The project department will strengthen communication with various units, especially the monitoring units of the track, to identify and rectify problems in a timely manner, and strengthen monitoring.

7. Conclusion

To sum up, it is necessary to pay attention to the overall safety of the deep foundation pit support construction for adjacent metro project, which shall be discussed and studied from multiple dimensions such as design and construction. According to the actual geological survey and subway location of the project, it is necessary to pay attention to the safety of construction technology during the selection of appropriate design plan and construction. So as to ensure the effectiveness and the stability of the overall quality of the deep foundation pit support construction of the adjacent subway engineering. Meanwhile, the construction shall be conducted in strict accordance with the engineering construction standards, laying a good foundation for the construction of the adjacent subway project, providing convenience for people and ensuring the safe operation of the subway.

References

- [1] Xiao Yu, Dong Yanzhao. *Numerical Simulation Study on Construction Process of Foundation Pit Project Adjacent to Existing Urban Rail Transit Structure*. *Value Engineering*, 2022, 41(14):3.
- [2] Yan Jingya. *Design and Construction of Deep Foundation Pit near Metro Tunnel*. *Chinese Journal of Geotechnical Engineering*, 2010(S1):4.
- [3] Cui Xuezhong. *Design of deep foundation pit adjacent to the operating subway line*. *Protective Engineering*, 2019
- [4] Xue Zhisong. *Construction of Large-Scale Deep Foundation Pit Adjacent to Subway*. *Building construction*, 2022(44)5.
- [5] Wang Wenming. *Application of high pressure jet grouting pile in soft foundation treatment of road and bridge*. *China high-tech enterprises*, 2012(17):3.
- [6] Liang Zhixin. *Talking about the key points of deep foundation pit enclosure construction near subway*. *Architectural Engineering Technology and Design*, 2018.
- [7] Yan Zhenghong. *Research and application of earth work staggered excavation in adjacent deep foundation pits*. *Building construction*, 2022.
- [8] Wu Xiaohui. *Analysis of external engineering Safety Monitoring and Management in urban rail transit control and protection*. *Protective Engineering*, 2018
- [9] Qin Zhenggang. *Discussion on planning and construction control of adjacent plots of urban rail transit*. *Architectural Engineering Technology and Design*, 2015, 000(015):32,188.
- [10] Li Jichao; Zhu Junpu; Xing Houbing; Qiu Yunjun; Zheng Shuang; Wang Xiangqiu. *Back Analysis of Seepage Parameters of Deep Foundation Pit Engineering of Subway Station under Complex Geological Condition*, *Guangzhou Architecture*, 2021.